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ACTIVE TESTING SURVEILLANCE SYSTEMS, OR, PLAYING TWENTY QUESTIONS WITH A RADAR

Daniel R. Fuhrmann

Department of Electrical Engineering
Washington University in St. Louis

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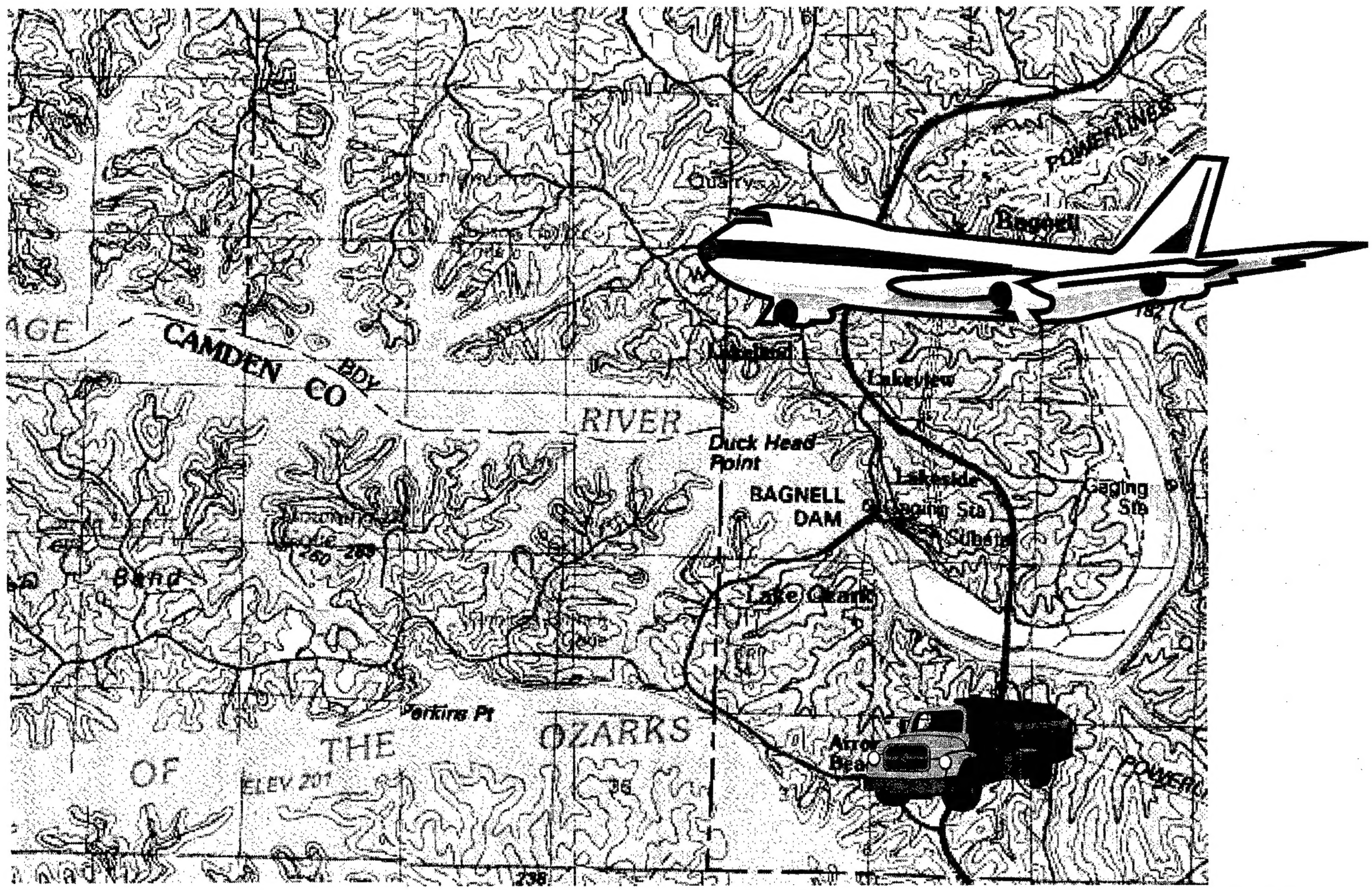
CONTEXT

- Airborne multisensor pulse-Doppler surveillance radar
- Ground moving targets (GMTI)
- Multiple targets
- Geographical side information (GIS)
- Platform side information (GPS, INS)

CONTEXT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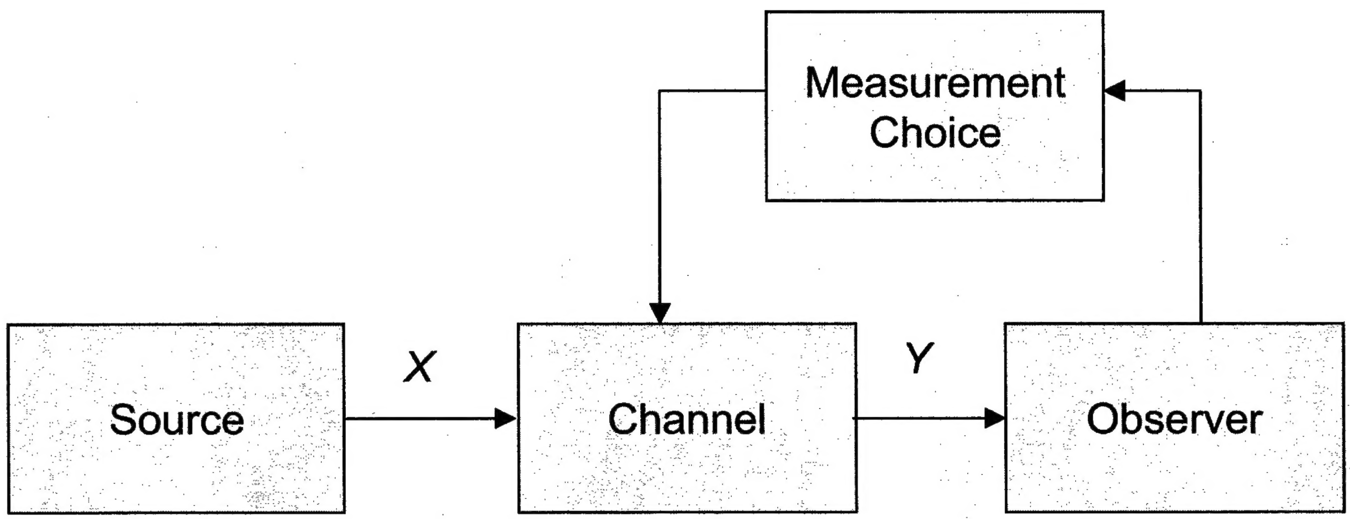
ACTIVE-TESTING SURVEILLANCE SYSTEM



A communication system in the usual information-theoretic sense, with the added feature that the channel can be manipulated by the observer.

GENERAL APPROACH

The goal of a surveillance system is to minimize the entropy of the posterior distribution of the source vector X.

- Entropy definition:

$$H(X) = -\sum_{x} p_X(x) \log_2 p_X(x)$$

- Conditional entropy definition:

$$\begin{aligned} H(X|Y) &= -\sum_{y} p_Y(y) \sum_{x} p_{X|Y}(x|y) \log p_{X|Y}(x|y) \\ &= -\sum_{y} \sum_{x} p_{XY}(x,y) \log p_{X|Y}(x|y) \end{aligned}$$

SINGLE-MEASUREMENT STRATEGY

Choose that measurement which maximizes the mutual information $I(X,Y)$

- Mutual information definition:

$$\begin{aligned} I(X,Y) &= H(X) - H(X|Y) \\ &= H(Y) - H(Y|X) \end{aligned}$$

Repeated measurements: maximizing $I(X,Y)$ at each step seems obvious and intuitive, but is "greedy" and may not be globally optimal.

TWENTY QUESTIONS

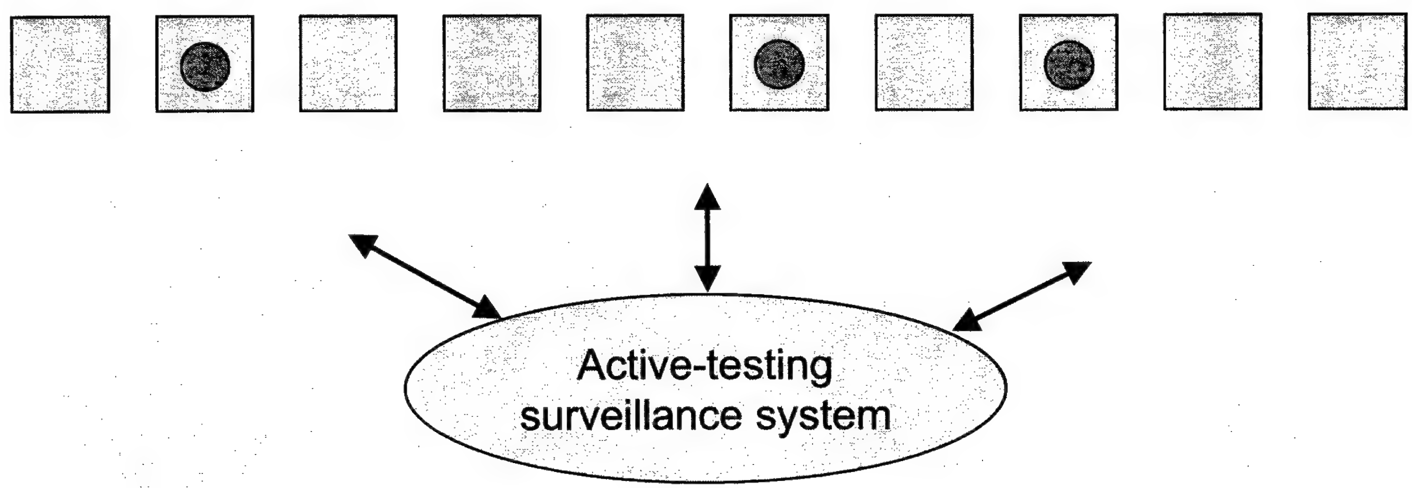
- A game in which the objective is to determine the correct answer by asking the right questions in the right order.
- Perhaps “Battleship” or “Mastermind” is a better analogy, since there is more feedback from observation to question.
- Connection with source coding: in binary coding, each bit represents the answer to a YES/NO set membership question. We like each bit to be maximally informative. If the bits are determined sequentially this is like Shannon-Fano coding. The globally optimum code is the Huffman code.

SAMPLING OF RELEVANT LITERATURE

- Sequential detection: Berger (1980)
- Experimental design: Carlin and Louis (1996)
- Coding theory connection: Goodman and Smyth (1988)
- Selection of maximally informative measurement:

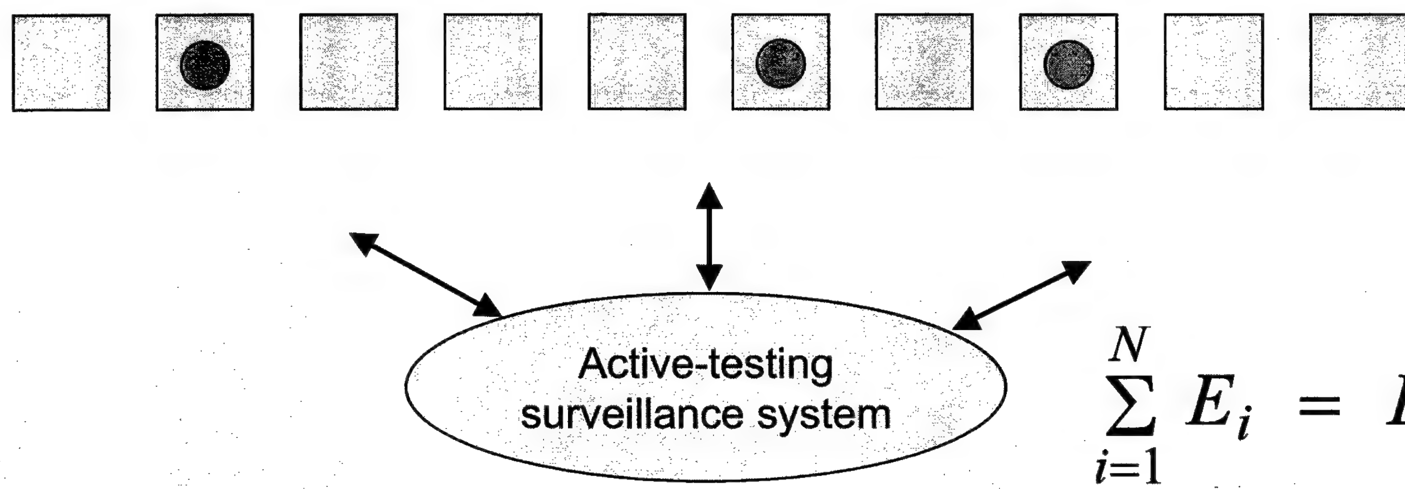
  Lewis (1962)
  Pearl (1988)
  Geman and Jedynak (1996)
  Yuille and Coughlan (2000)

MULTIPLE TARGET DETECTION SCENARIO



- N independent cells
- Each cell defines a binary hypothesis testing problem
- Divergence between H0 and H1 depends on transmitted energy

FINITE-ENERGY CONSTRAINT

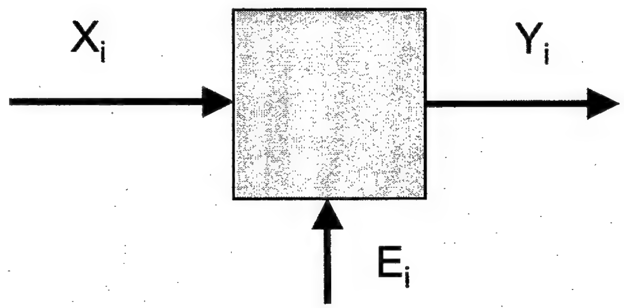


$$\sum_{i=1}^{N} E_i = E$$

- What is the optimum partition of the available energy E?

SIMPLE DATA MODEL

- Each cell acts like a binary symmetric channel (BSC):



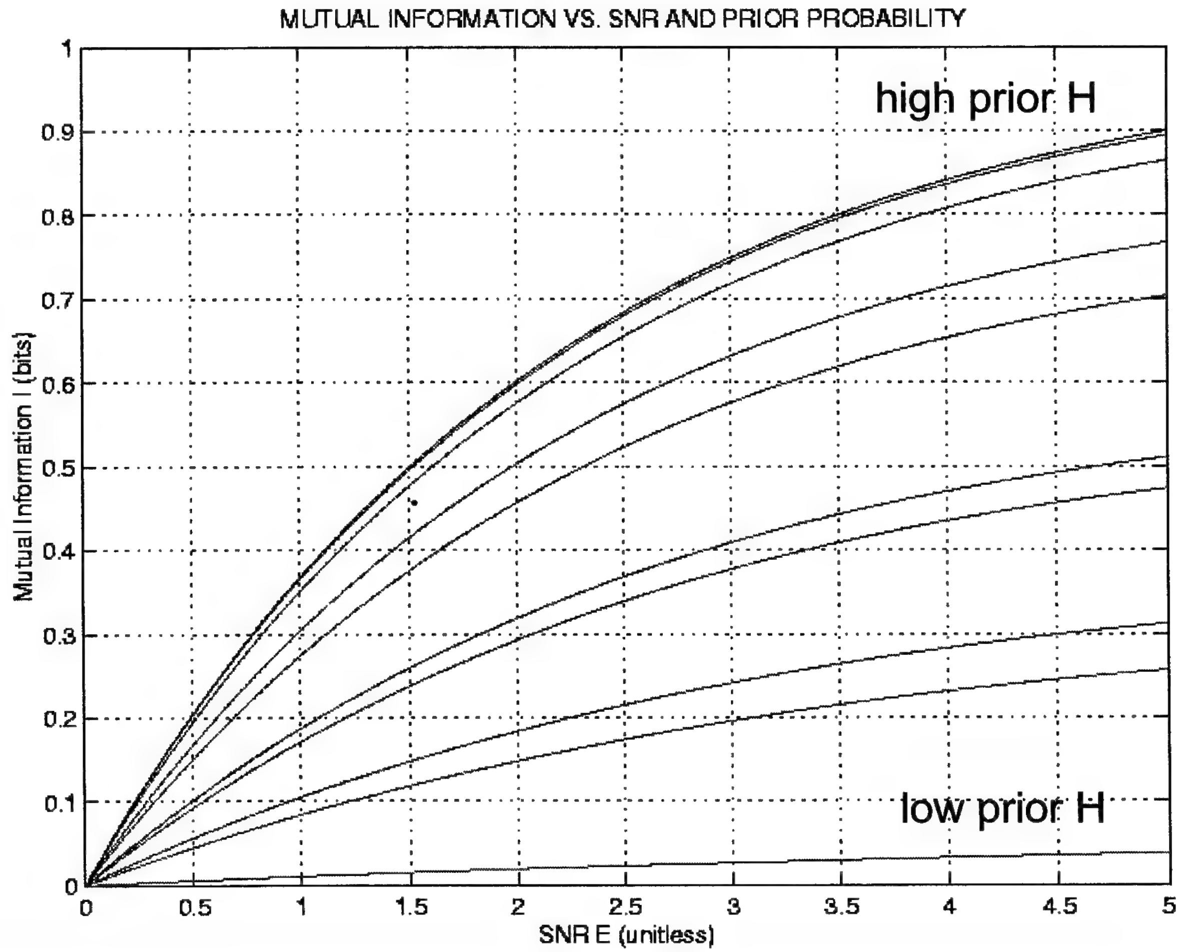
$$Y_i = sign(W_i)$$

$$H_0: \; W_i \sim N(-\sqrt{E_i}, \sigma^2)$$

$$H_1: \; W_i \sim N(+\sqrt{E_i}, \sigma^2)$$

$$\boxed{P_{e,i} = 1 - \Phi\left(\frac{\sqrt{E_i}}{\sigma}\right)}$$

FAMILY OF I(X,Y) vs. SNR CURVES



OPTIMIZATION OF ENERGY PARTITION

- Optimization problem:

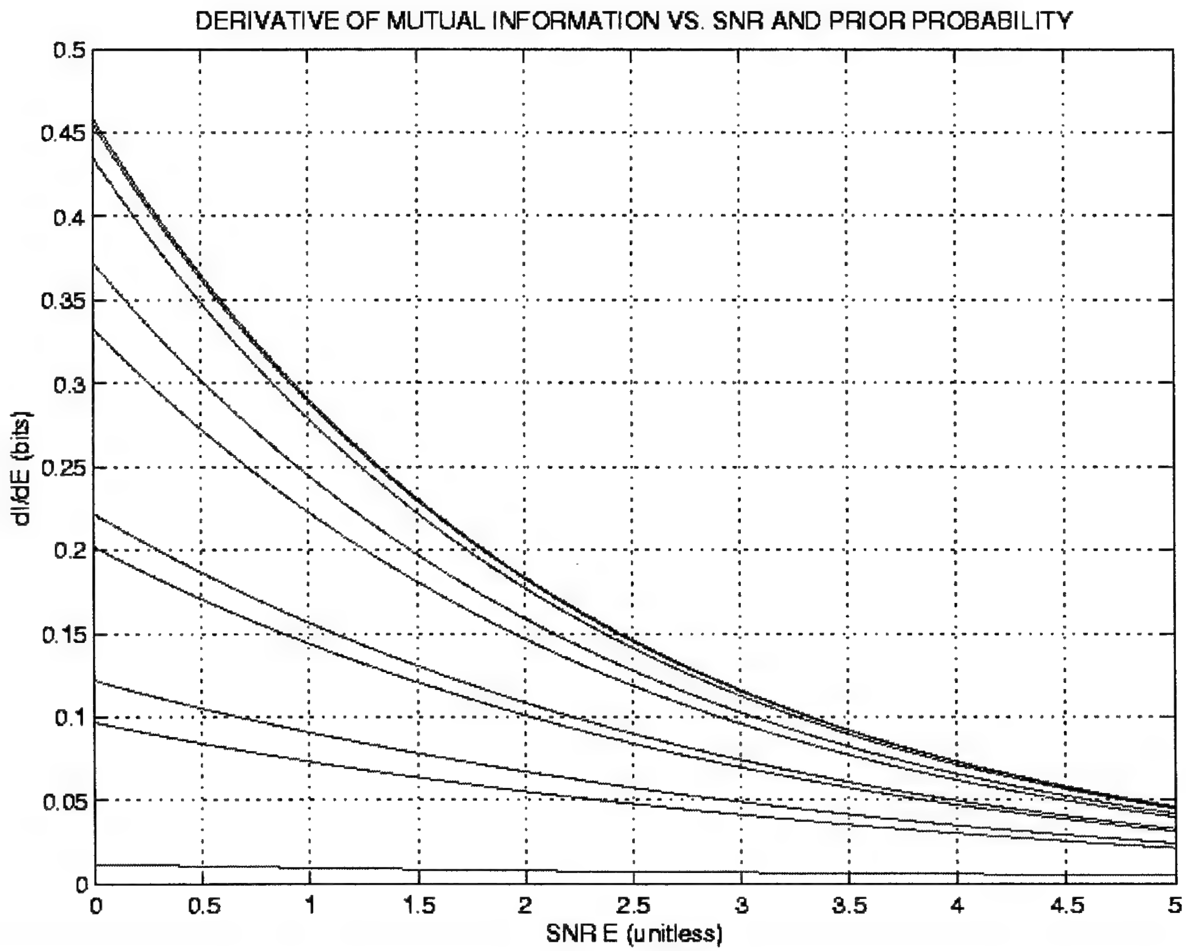
$$\max_{\{E_i\}} \sum_{i=1}^{N} I(X_i, Y_i; p_i, E_i) \qquad \text{s.t.} \quad \sum_{i=1}^{N} E_i = E$$

- Kuhn-Tucker conditions:

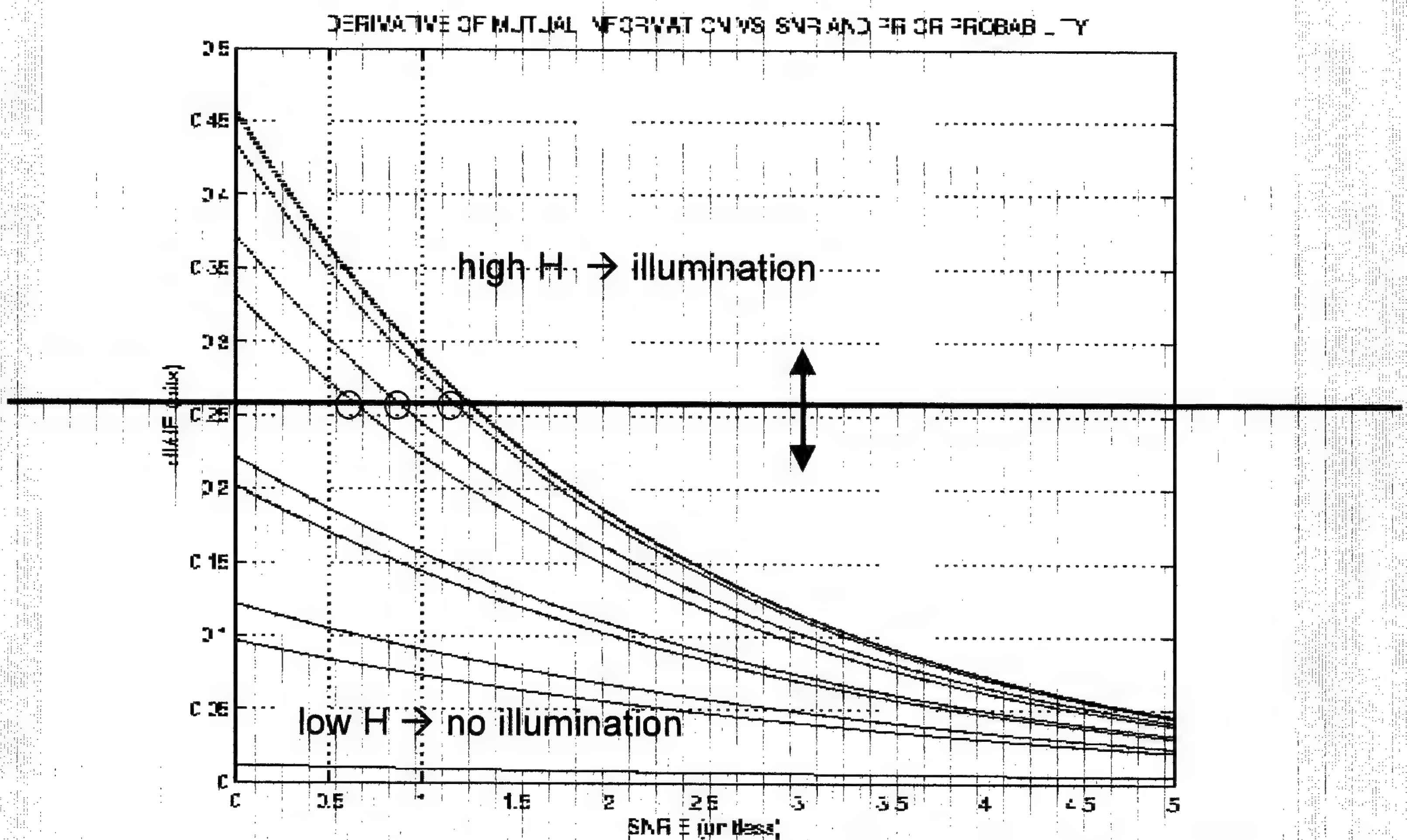
$$\text{If } E_i \neq 0, \quad \text{then } \frac{\partial I}{\partial E_i} = \lambda$$

$$\text{If } \frac{\partial I}{\partial E_i} < \lambda, \quad \text{then } E_i = 0$$

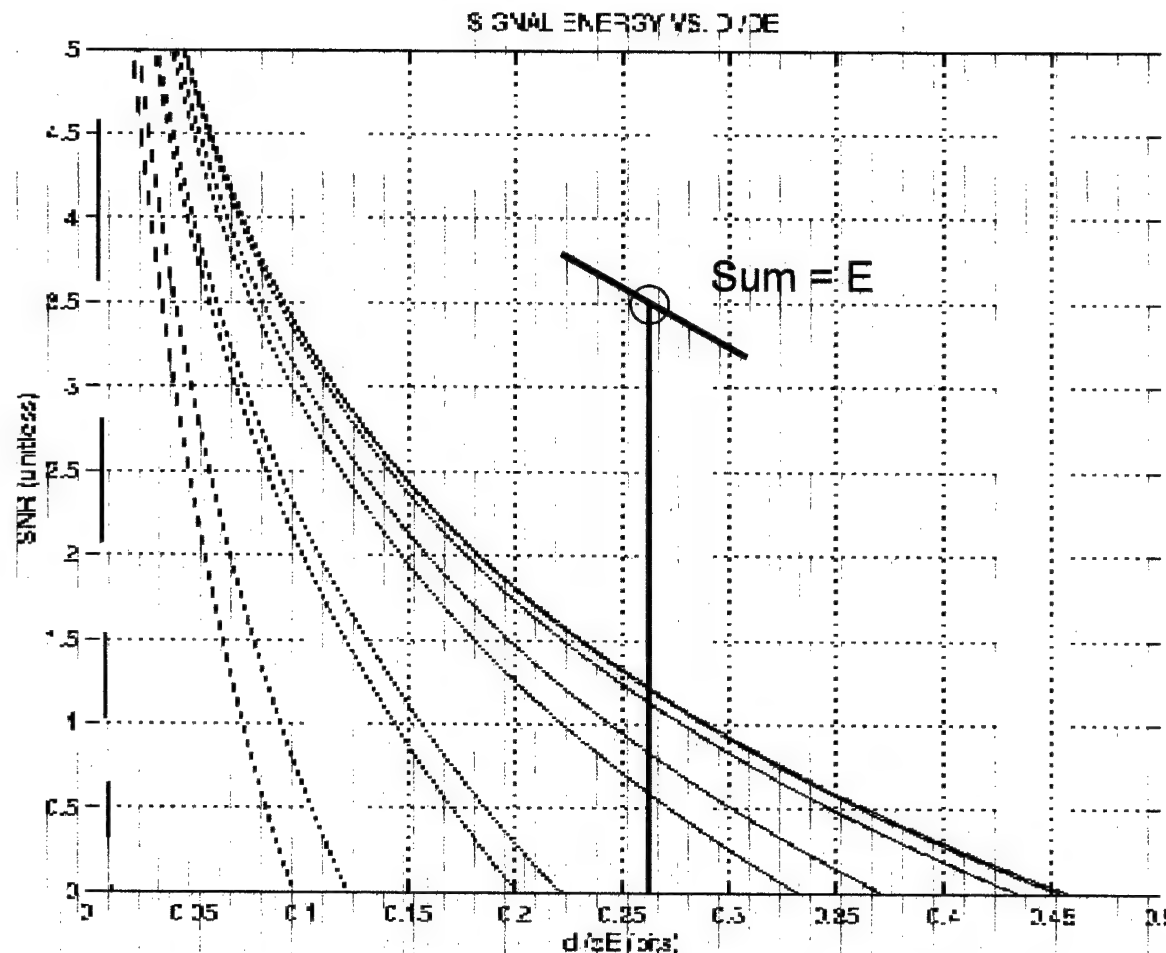
FAMILY OF dI/dE CURVES



FINDING THE OPTIMAL PARTITION

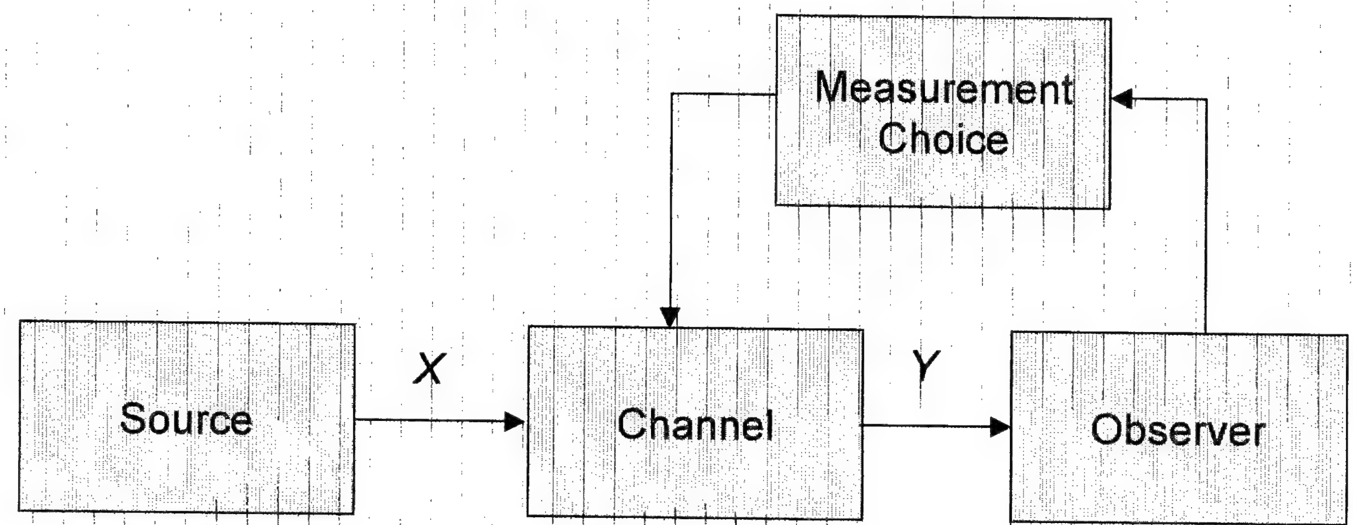


OPTIMAL PARTITION (ALTERNATE VIEW)

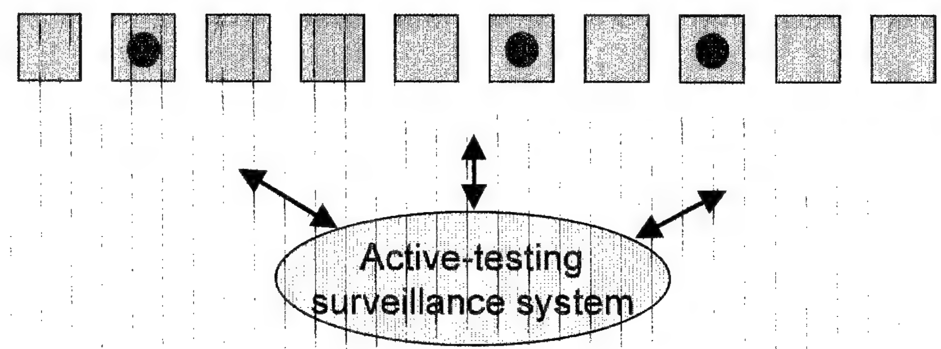


ACTIVE TESTING, AGAIN

Use optimal partition of energy,
as previously derived

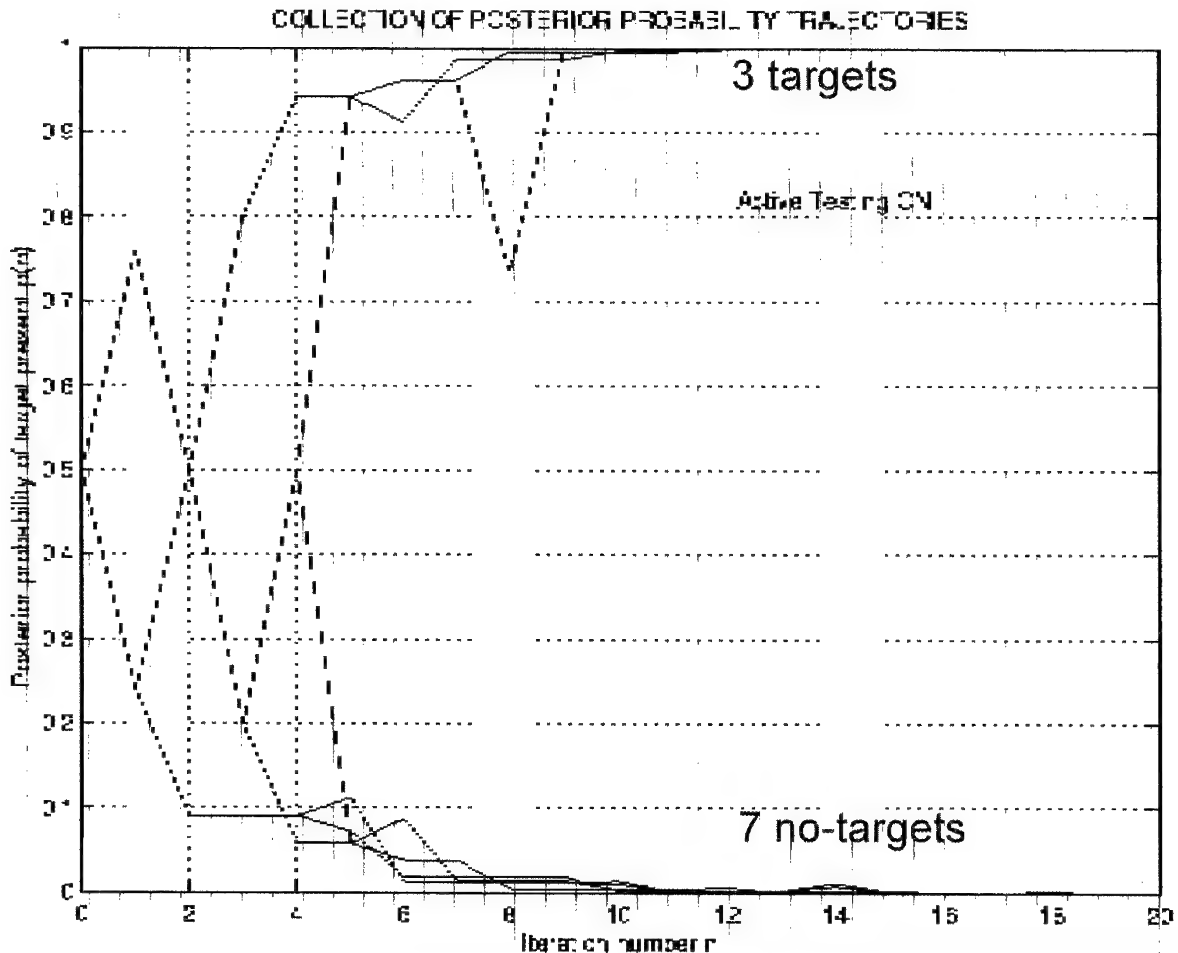


SIMULATION SET-UP

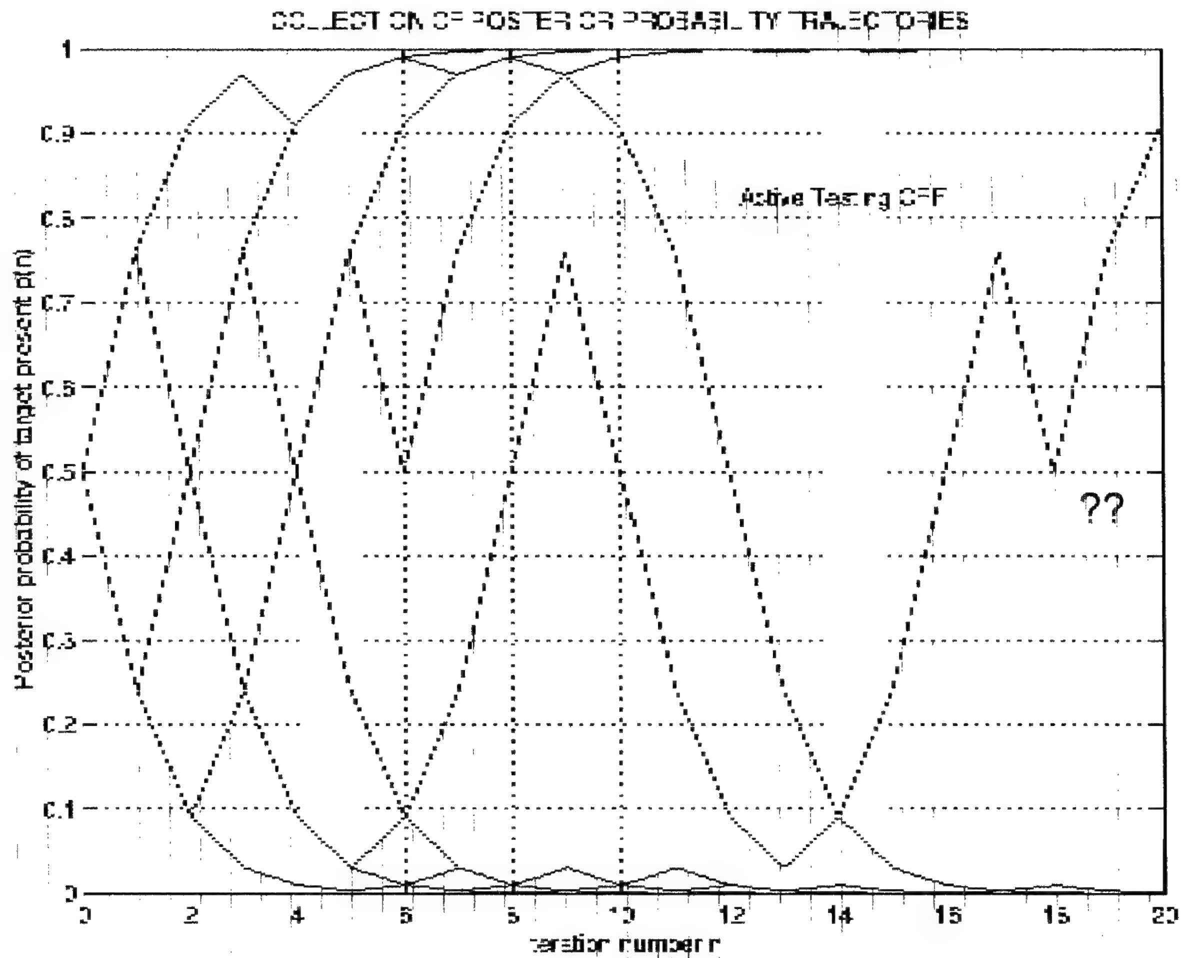


- N = 10 cells
- Total energy E = 5
- 0 dB noise
- Targets in 3 cells
- Prior probability of target present = 0.5, all cells

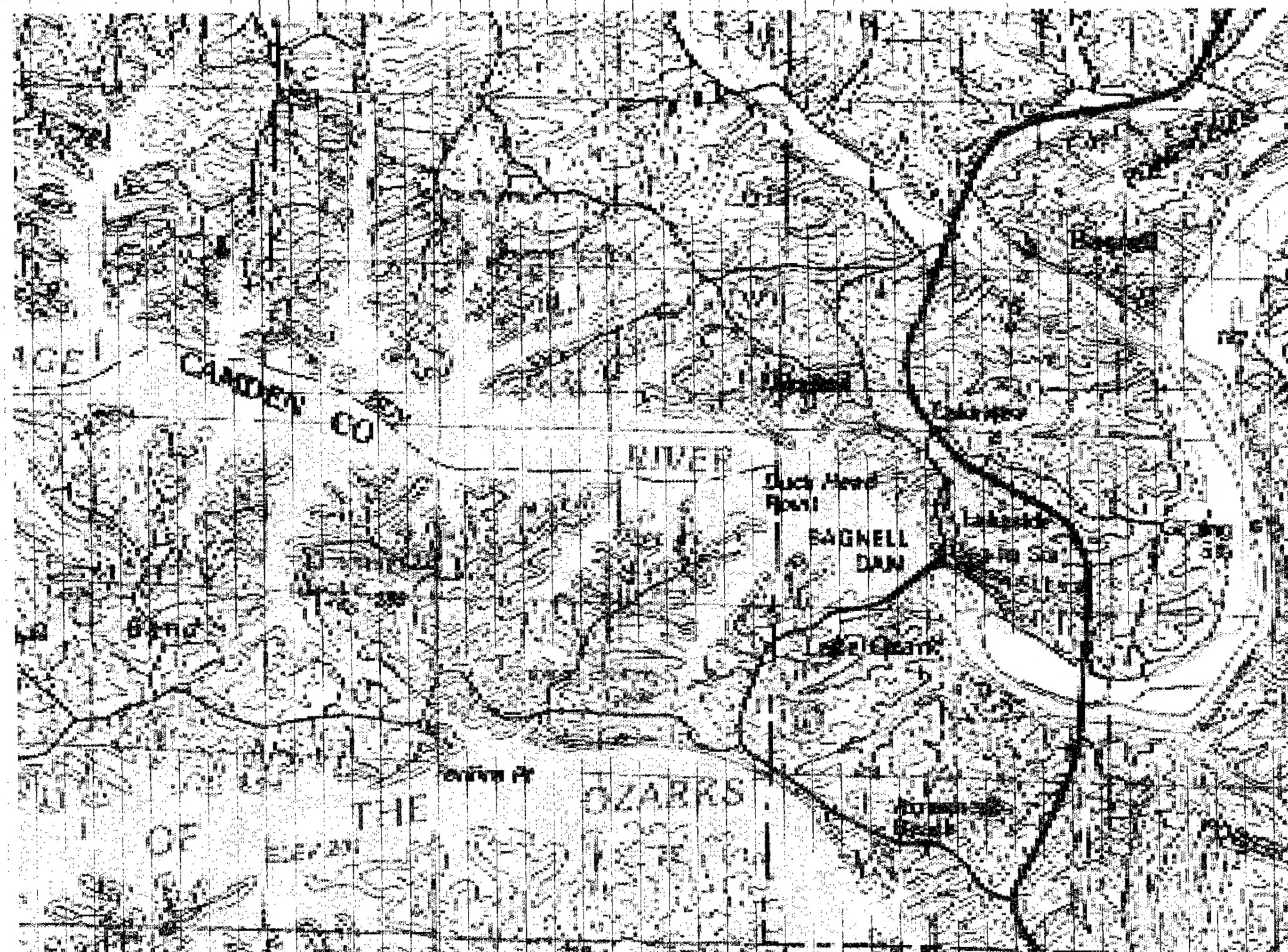
SEQUENTIAL DETECTION, ACTIVE TESTING ON



SEQUENTIAL DETECTION, ACTIVE TESTING OFF



WHERE DO WE GO FROM HERE?



RESEARCH AIM

To investigate the feasibility of active-testing surveillance systems in the context of:

- Airborne multisensor pulse-Doppler surveillance radar
- Ground moving targets (GMTI)
- Multiple targets
- Geographical side information (GIS)
- Platform side information (GPS, INS)

IMMEDIATE GOALS

- Merge terrain-based radar simulation and active testing
- Incorporate linear constraints in illumination patterns (i.e. beamforming)
- Allow different clutter and target signatures in cell (targets are moving
- Include adaptive processing for interference

CONCLUSION

We have:

- introduced the concept of active-testing surveillance systems
- considered multiple-target detection
- derived numerical solution to optimization problem of distribution of finite illumination energy
- shown anecdotal result that active testing improves convergence in sequential detection
- indicated future research directions in airborne multisensor pulse-Doppler surveillance radar